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TREATMENT OF DILUTE LANDFILL GAS BY OPEN BIOCOVER SYSTEMS - COLUMN EXPERIMENTS

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SUMMARY: Large amounts of methane are emitted from landfills in dilute form due to mixing with air in leachate collection systems, or during lateral migration away from landfills. The aim of this study was to investigate the methane oxidation efficiency of a compost material subject to diluted landfill gas with concentrations of 5-10 % methane. The study was performed by a laboratory column experimental setup supplied with an increasing inflow of gas through five measuring campaigns. Column gas concentration profiles for each of the five flow campaigns showed that the methane oxidation process tended to be centred in the lower parts of the columns. An increasing methane removal rate was observed through the flow campaigns with a maximum methane oxidation rate of $509 \mu\text{g CH}_4/\text{m}^2/\text{d}$. The results of this study suggest that compost-based biofilters have great potential for reducing methane contained in diluted landfill gas.

1. INTRODUCTION

Landfills contribute with a significant amount of landfill gas (LFG) emissions, containing methane (CH_4). Landfills are significant sources of anthropogenic atmospheric CH_4 , which contributes to climate change. Large amounts of LFG are emitted in dilute form due to mixing with air in leachate collection systems (Fredenslund et al., 2010). At old landfills, LFG may laterally migrate into surrounding residential areas. This has often been avoided by installation of wells at the perimeter of the landfill extracting pore gas containing low concentrations of CH_4 and high concentrations of oxygen (O_2). The extracted pore gas is in most cases vented directly to the atmosphere (Kjeldsen, 1996). In both cases the LFG is so dilute that it becomes economically infeasible to utilize. To reduce LFG emissions, biocover systems constitute a low-cost alternative to LFG utilization (Kjeldsen & Scheutz, 2014). Such biocover systems will, due to the dilute nature of the LFG, be loaded with a mixture of CH_4 and O_2 and thus differ from traditional biocover systems loaded by O_2 -free LFG.

The aim of this study was to investigate the CH_4 oxidation efficiency of a compost material subject to diluted LFG with content of CH_4 (5-10 % CH_4 v/v) and O_2 (15-20 % O_2 v/v) using a column experimental setup loaded with increasing inflows of gas.

2. MATERIAL AND METHODS

2.1 Sampling and characterization of compost material

The compost used in this experiment was a yard-park compost collected from the recycling company, RGS 90, Copenhagen, Denmark. The compost was collected from a compost windrow. The characterization of the compost was done based on the following parameters; moisture content, loss of ignition (LOI) and bulk density. The moisture content and LOI were determined gravimetrically by weight loss after 24 hours at 105 °C and weight loss after 3 hours, respectively. To ensure that the compost had potential of methane oxidation, standard batch incubations were performed to determine the potential CH₄ oxidation rates and respiration rates. The batch experiments were carried out by adding 100 g of moist compost into 500 mL incubation glass bottles. More details of the performance of similar batch tests can be found in Scheutz et al. (2014).

2.2 Column experimental setup

Three rigid PVC columns (h = 100 cm; i.d. = 20 cm) were used to examine the CH₄ oxidation process; one control and two experimental columns. The experimental setup resembled an open biocover system where oxygen can diffuse into the compost material from above. Column gas concentration profiles for each of five flow campaigns were compared to each other.

The control column was packed with gravel with 2.00-3.55 mm grain size whereas the active columns were packed with the sampled compost. A 3 cm gravel layer was distributed in the bottom on top of a perforated nylon net to ensure a homogeneous gas distribution to the layer of compost. Sampling ports were placed alongside the column length with 5 cm between each port and the bottom port being located 5 cm from the bottom inlet. A flow of pure CH₄ mixed with atmospheric air was fed into the bottom using peristaltic pumps. The column headspace was fed with a constant ambient airflow of in average 109 mL/min using a vacuum pump. This was done to simulate atmospheric conditions in the top chamber and thus supplying O₂ by vertical diffusion into the compost material.

The principle of the column experimental setup is shown in Figure 1. The column experiment was carried out at room temperature (approximately 20-22°C). Table 1 shows an overview of the CH₄ and air inlet flows to the columns, together with column CH₄ loads. In order to study the methane oxidation capacity of biofilters at different CH₄ loadings, the column experiments were run with five different inlet flows ranging from 5-150 mL/min (total inlet flow) and two different inlet CH₄ concentrations (5 or 10 % v/v) (Table 1). The experiment was divided into five measuring campaigns each of 14 days and with increasing CH₄ loadings to the columns. During each campaign gas samples were taken (inlet, outlet and sampling ports) five times during the 14 day duration of each campaign. The gas samples taken from column experiments (as well as the batch incubation experiments) were analysed for contents of CH₄, O₂, carbon dioxide (CO₂) and nitrogen (N₂) using gas chromatography on a 490 Micro GC (Agilent Technologies, USA).

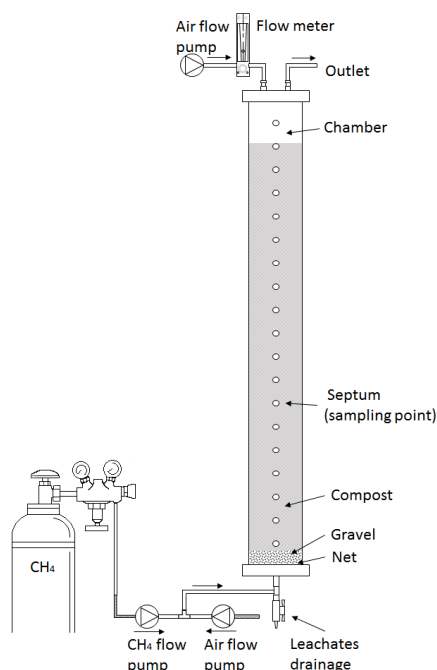


Figure 1: Conceptual column setup of the dynamic column.

Table 1. Overview of the column set-up showing planned inlet bottom flows, and CH₄ loadings.

Column no.	CH ₄ inlet conc. [% v/v]	Total inlet flow [mL/min]	CH ₄ inlet flow [mL/min]	Total inlet flux [m ³ /m ² /d]	CH ₄ load [g CH ₄ /m ² /d]
C.+1+2	5	5	0.25	0.229	7.64
C.+1+2		25	1.25	1.15	38.2
C.+1+2		50	2.50	2.29	76.4
C.+1		75	3.75	3.44	115
C.+1		150	7.50	6.88	229
2	10	75	7.50	3.44	229
2		150	15.0	6.88	458

3. RESULTS AND DISCUSSION

3.1 Compost material characteristics

From the performed compost analysis, the gravimetric water content was found to be 57 % dry matter (DM), while the water content based on the wet weight of the compost was 36 % w/w (wet weight). The organic matter content was 24 % of DM, and the bulk density of the compost was 0.55 kg/L. From the batch incubation experiment it was observed that the CH₄ oxidation rates ranged from 19 to 34 µg CH₄/gDW/h, while the O₂ consumption during the respiration test was 21 µgO₂/gDW/h. This value is well below the recommended maximum respiration rate of <48 µgO₂/gDW/h, (calculated from <8 mgO₂/gDW) recommended by Humer & Lechner (2001).

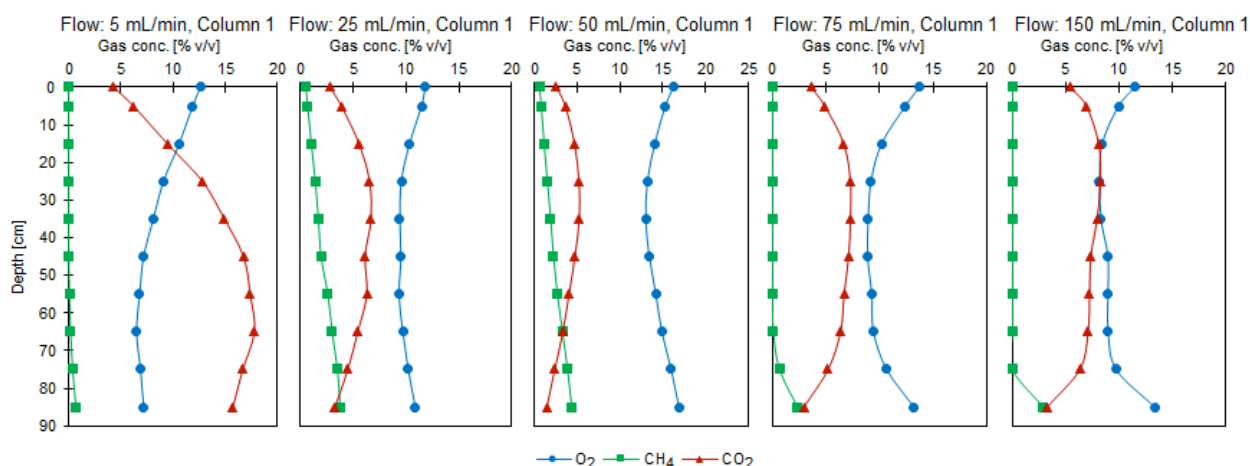


Figure 2. Gas concentration profiles for Column 1 with 5 % CH_4 (v/v) inlet flow concentration: (A) day 14 during 5 mL/min flow, (B) day 14 during 25 mL/min flow, (C) day 14 during 50 mL/min flow, (D) day 14 during 75 mL/min flow and (E) day 14 during 150 mL/min flow.

3.2 Column test – Gas concentration profiles

Figure 2 presents a collection of gas concentration profiles for Column 1 obtained on the last day of each flow campaign. During the first campaign, all the CH_4 was oxidised already in the lowest part of the column and the highest level of CO_2 production was detected (17.8 % v/v) during this campaign. However, it is most likely that some of this CO_2 could be from the compost respiration rather than from the CH_4 oxidation process. During the two next flow campaigns (inlet flows of 25 and 50 mL/min), CH_4 was present in all depths of the column, and it was seen that the concentrations of CO_2 was lower during these two flow campaigns. No time-dependent variation in the profiles during the 25 mL/min flow campaign were observed (data not shown), which indicates that the column reached steady state, obtaining a maximum oxidation efficiency for this flow condition. However, the last two sub-figures in Figure 2 from day 14 for the 75 and 150 mL/min flow campaigns show that the column was able to completely oxidise CH_4 locally in the bottom part of the column, the lowest 25 cm and 15 cm, respectively. This indicates that the bacterial population in the column, during the first inlet flow campaigns (1 to 3) had an adaption period and was thereafter capable of completely oxidising the higher CH_4 loads.

Figure 3 presents the five measured gas concentration profiles from the 75 mL/min flow campaign for Column 2. These profiles are very different from what was found in Column 1, probably as a result of the higher CH_4 loading concentration. The figure shows a significant development of the shape of the gas concentration profiles through the 14 day duration of the flow campaign. The gas concentration profiles show gradually higher oxidation capacity indicating a development of the methanotrophic population. This is seen by the decrease in CH_4 and O_2 concentrations and an increase in the CO_2 concentrations. CH_4 is detected throughout the entire column in the beginning of the campaign; decreasing from the bottom of the column to the top with a starting point around 4-5 % CH_4 (v/v). As the inlet flow is kept constant during the 14 days, the CH_4 is more efficiently oxidised in the bottom of the column and thus leaving less gas to penetrate the remaining upper part of the column. Furthermore, the figure reveals that the biofilter could have been exposed to a greater mass of CH_4 in the inlet flow as it is able to completely oxidise CH_4 . The development of the O_2 consumption is also interesting in these profiles. The additional O_2 supply in the bottom of the column seems to have a positive effect on the oxidation process as the microbial population does not become limited by O_2 in the deep

part of the column, which has been seen in other comparable column studies (Scheutz et al., 2009).

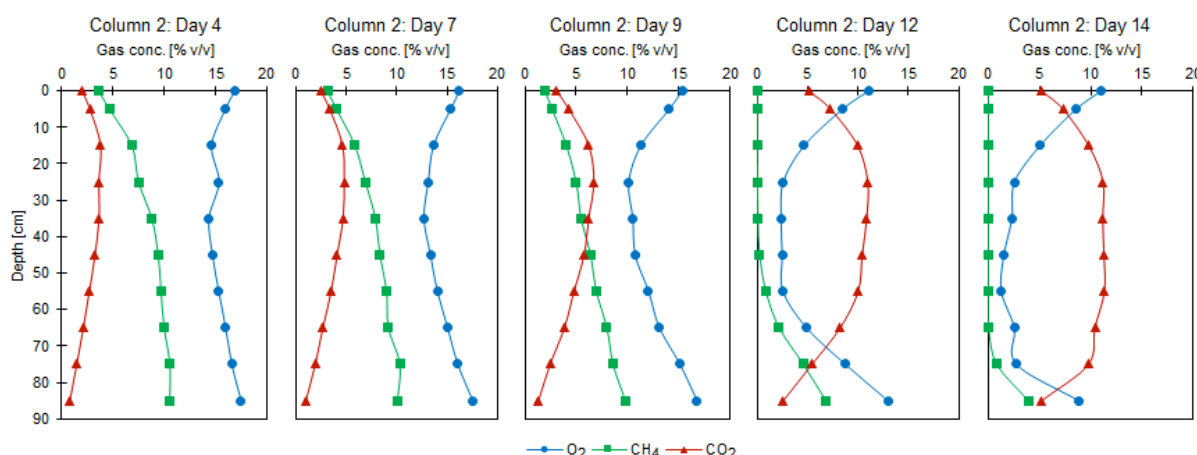


Figure 3. Gas concentration profiles for Column 2 during the 75 mL/min flow campaign and 10 % CH₄ (v/v) inflow concentration: (A) day 4, (B) day 7, (C) day 9, (D) day 12 and (E) day 14.

Table 2. Overview of column results showing average input CH₄ loads, CH₄ oxidation results and carbon mass balances during the five inlet flow campaigns in the three columns.

Column	Campaign	Inlet flow [mL/min]	Retention time [h]	Initial conc. [% CH ₄]	CH ₄ load [g CH ₄ /m ² /d]	CH ₄ oxidation efficiency [%]	CH ₄ oxidation rate [g/m ₂ /d]
Column 1	1	6.03	30.1	4.44	8.19	100	8.19
	2	24.8	7.33	4.96	37.5	51.6	19.3
	3	49.7	3.65	5.01	76.1	47.9	36.3
	4	75.5	2.40	4.88	113	94.4	107
	5	150	1.21	5.21	238	100	238
Column 2*	3	49.7	3.66	5.10	77.5	30.4	23.5
	4	74.7	2.43	9.57	218	63.1	137
	5	151	1.20	10.6	488	99.0	483

*For Column 2 only results from campaign 3 to 5 are shown due to a leakage during campaign 1 and 2

3.3 Methane oxidation rates and efficiencies

Table 2 provides an overview of the column results showing retention times, column CH₄ loads (g/m²/d), CH₄ oxidation rates (g/m²/d), and CH₄ oxidation efficiencies (%).

The maximum removal efficiency of CH₄ was found to be 100 % in both columns with an average of 78-79 %. Using CH₄ mass balances the maximum oxidation rate of one of the columns was 253 g CH₄/m²/d (equal to the load), while the other column, subject to higher loads (458-525 g CH₄/m²/d), had a maximum oxidation rate of 509 g CH₄/m²/d. None of the two

compost columns reached their maximum oxidation capacity, hence they could have been exposed to a larger CH₄ load. It was found that the retention time in the columns was not a limiting factor to the oxidation process. High O₂ consumption underlined the high activity in the columns and it was not suspected that the methanotrophs were O₂ limited.

4. CONCLUSIONS

Laboratory columns simulating a biofilter fed at the bottom with diluted LFG and open to the atmosphere at the top were constructed and supplied with five different CH₄ inlet flows (5 to 150 mL/min) containing 5 or 10 % v/v CH₄. Column gas concentration profiles suggested high methanotrophic activity in the lower parts of the columns. At all tested column inlet flow rates and CH₄ loads, O₂ penetrated the entire column, and hence O₂ was not a limiting factor for the oxidation process during the experiment. During the run of the experiment, the microbial population adapted to CH₄ oxidation during the initial test campaign with lower CH₄ inlet flows and were able to completely oxidise the fed CH₄ during the highest inlet flows. The highest CH₄ oxidation rate found was around 500 g/m²/d, and even at this CH₄ load, the fed CH₄ was completely oxidized indicating that the maximum oxidation capacity of the column had not been reached. The results of this study suggest that biofilters has great potential for reducing CH₄ contained in diluted LFG containing elevated concentrations of O₂.

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